Effects of Moderate Altitude on patients with Pulmonary and Cardiac Impairment

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■ *Twenty ambulatory patients with severe chronic pulmonary disease and 24 with severe heart disease were exposed in an altitude chamber to a simulated altitude of 8000 feet such as might exist in pressurized aircraft. Eight of the patients in the pulmonary group experienced undesirable reactions related to hypoxia, hypoventilation, inability to hyperventilate and expansion of gases. None of the 24 patients with cardiac disease experienced this same difficulty and all tolerated the procedure well. The ability to tolerate the stress of moderate altitude is related more to ventilatory efficiency and the maintenance of adequate oxygen saturation than to cardiovascular factors.*

It is recommended that a thorough evaluation of the cardio-pulmonary patient by clinical and physiological tests be made before exposure to altitude. When severe impairment is demonstrated, the subject may still be able to tolerate moderate altitudes if appropriate measures are provided to cope with the altered physiologic conditions.

FREQUENTLY a patient with a cardiac or pulmonary disorder asks whether he may safely expose himself to moderately high altitudes (up to 10,000 feet). The question may arise in planning a vacation, trip, pilgrimage, transfer to a medical clinic or for other similar situations.

To answer such a question intelligently it is necessary to know the disease process, how much it limits functions, the mode of travel, the duration of exposure, the purpose of the trip and the activity involved (Table 1).

Exposure to altitude is common; it may be acute, subacute or chronic. This discussion will deal only with acute exposures such as may occur in flight and other forms of travel.

Extensive surveys and studies have been made in reference to air travel. For the most part the reports support the general point of view that any passenger able to walk up a loading ramp can tolerate the stresses of a commercial passenger trip or if he can travel at all he can travel safely by air. Although safe for the majority, altitude imposes a risk to a few. Provision of measures to counteract the effects of altitude will allow these few to make a trip comfortably and safely.

The normal person can ascend to and tolerate an altitude of 5,000 to 10,000 feet without ill effects, experiencing only minor visual defects, easy fatigue and shortness of breath on effort. He adjusts by increasing ventilation and circulation.

Patients with cardio-pulmonary diseases require particular attention since adjustments to altitude are primarily pulmonary and circulatory. A majority of the deaths in civilian air transportation have been reported as cardiac or pulmonary.[2] Marberger and coworkers demonstrated that patients with angina, when exposed to altitudes of 8,000 to 18,000 feet, experience increased frequency of attacks and show electrocardiographic and other changes, relieved by administration of oxygen.[6]

With regard to pulmonary conditions, the committee on respiratory physiology of the American College of Chest Physicians has published specific criteria for passenger flight. By these criteria a passenger, after medical appraisal, is placed in one of five categories with allowable cabin limits from 2,000 feet to a top of 10,000 feet. Respiratory acidosis and ventilatory restriction were stressed as the most important limiting factors.[1]

Gordon, Wilson, Stonehill and Morsey, in discussing air travel by patients with respiratory diseases, pointed out that serious obstructive impairment (emphysema), restrictive abnormalities (effusion and fibrosis) and gas exchange defects present problems in connection with air travel.[4] They recommended that patients should not go above 8,000 feet—6,000 feet if cyanosis is present, and 4,000 feet if emphysema with acidosis exists. With oxygen supplementation, they believed any patient could fly. They advised against administration of oxygen in respiratory acidosis.

In discussing considerations in selecting airline passengers, Kidera,[5] set down criteria which, if followed, would keep many patients from traveling by air.

The U.S. Air Force has evacuated over 2,000,000 patients by air ambulance. Downey and Strickland analyzed 1,800 flights of patients with cardiac and pulmonary diseases, including myocardial infarction and pneumothorax, without apparent deleterious effects or contraindication to flight transportation. These flights, however, were made with well trained personnel and adequate facilities available.[3]

Methods and Procedures

In order to test the ability of patients with cardiorespiratory diseases to tolerate moderate altitudes, an altitude tolerance test was devised. The proce-

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TABLE 1.—*Actual Altitudes as Compared With "Cabin Altitudes" in Six Aircraft Commonly Used by American Carriers*

	Simulated (Cabin) Altitude, Feet, in					
Ambient Alt., feet	*Boeing 707*	*Douglas DC-8*	*Lockheed Electra*	*Vickers Viscount**	*Douglass DC-7*	*Convair 240*
40,000	7,500	7,000				
35,000	5,500	5,000				
30,000	3,700	3,200	8,000			
25,000	1,400	1,000	5,400	7,900	8,000	
22,500	Sea level	Sea level	4,100	6,510	6,500	
20,000			2,650	4,930	5,000	9,700
15,000			Sea level	1,750	1,800	6,000
10,000				Sea level	Sea level	2,000
7,500						200
5,000						Sea level

* Usually operated at a pressure of 5.5 lb. per square inch.
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dure consisted of exposing selected patients to altitudes in a decompression chamber. This chamber consisted of main and lock sections designed for physiologic monitoring and communication. The main portion was sufficiently large to accommodate a physician observer, a flight nurse and the subject. Seats of the kind used in airlines were installed and there was adequate room for limited movement about the chamber. Outside were a physician-observer and the operator of the chamber.

Twenty patients with chronic pulmonary disease[7] and 24 with heart disease were selected for the study. The main criteria for selection was that the patients be ambulatory. All patients in the pulmonary group had severe disease with pronounced impairment and their condition was evaluated from a clinical and physiological standpoint before they were exposed to the simulated high altitude. A preflight physical examination was done just before they entered the chamber. "Ascent" was made at 300 feet per minute. At 2,000 feet basic measurements such as pulse, temperature, blood pressure, oximetry, pulmonary function, electrocardiographic and respiratory rate were recorded. During an exercise the pulse rate, respiration, an electrocardiogram and other indicative phenomena were monitored. The exercise test consisted of 8-inch step-ups not exceeding 15 per minute. Ascent was made to 8,000 feet and then, after an appropriate waiting period, all the basic measurements were repeated. A meal equivalent in quantity and quality to that of a commercial airliner was served. Basic determinations were again carried out. Descent at approximately 300 feet per minute to ground level was made. The experiments lasted up to four hours.

TABLE 2.—*Major Diagnosis in 20 Patients With Pulmonary Disease Studied in Altitude Experiment*

	Number of Patients
Diffuse pulmonary fibrosis	1
Silico-tuberculosis	2
Histoplasmosis and emphysema	2
Emphysema	1
Pneumonectomies	13
Inoperable bronchogenic carcinoma	1

TABLE 3.—*Major Diagnosis in 27 Patients With Heart Disease Studied in Altitude Experiment*

Diagnosis	*Number of Patients*
Rheumatic heart disease (R.H.D. post-commissurotomy—3)	9
Arteriosclerotic heart disease (including angina pectoris)	7
Hypertensive cardiovascular disease	4
Myocarditis	3
Congenital heart disease (Atrial septal defect) (A.S.D. repaired surgically—1)	2
Leutic heart disease	1
Constrictive pericarditis	1

TABLE 4.—*Functional Classification of Cardiac Impairment in Patients Subjected to Altitude Tolerance Experiment*

A.H.A. Classification	*Number of Patients*	*Degree of Impairment*
Class I	2	No limitation of physical activity
Class II	10	Slight or moderate limitation
Class III	12	Marked limitation of physical activity

*American Heart Association.

Results

Results can best be described by dividing the patients into two separate categories, pulmonary and cardiac (Tables 2 and 3). The cardiac cases are further separated into a functional grouping, Table 4, in accordance with the American Heart Association functional classification.

Pulmonary

In the pulmonary group there were 16 males and four females ranging in age from 40 to 73 years of age. They had, variously, pulmonary fibrosis, silicotuberculosis, histoplasmosis, emphysema, carcinoma and postpneumonectomy. Many had a combination of disease processes. Pulmonary function abnormalities consisted of defects in diffusion, ventilation-perfusion, restriction of ventilation, obstruction to ventilation and respiratory insufficiency, alone or in combination.

To illustrate the severity of impairment, the vital capacity ranged from 775 cc to 4800 cc, the latter in a patient who had extensive emphysema with blebs and bullae. In 14 patients the vital capacity was below 50 per cent of predicted; in 19, below 75 per cent of predicted. Seven of the 14 with the vital capacity below 50 per cent tolerated the procedure well.

The maximal voluntary ventilation ranged from 20 liters per minute to 117 liters per minute. In the latter case the patient had a severe diffusion defect due to pulmonary fibrosis. He tolerated the altitude very poorly. Oxygen saturation was measured in only seven cases, in five of them it was below 90 per cent. These five tolerated the altitude poorly.

Twelve of the 20 patients with pulmonary disease satisfactorily tolerated the altitude exposure. The remaining eight had reactions which necessitated a modification in protocol to relieve their distress. In general if the maximal voluntary ventilation was below 40 liters per minute, altitude tolerance was poor. Fourteen of the pulmonary patients complained of dyspnea on exertion before the test. Five of the 14 tolerated the test satisfactorily. The complaint of dyspnea was not particularly helpful as a means of evaluation.

Cardiac

Twelve of the 27 patients with heart disease had cardiomegaly as demonstrated by x-ray films. Eighteen of them were receiving digitalis. Most had had congestive heart failure at some time previously. Several were receiving diuretic agents. In all of them, however, the heart condition was reasonably well compensated at the time of the altitude test. In this group, exercise was not attempted if the resting heart rate exceeded 120 per minute. The extent of exercise that was done as a part of the test was determined by the supervising physician from his pre-test observations and the clinical evaluation. For the patients on a low salt diet, the meal was modified appropriately. Studies of vital capacity, expiratory flow, blood pressure, pulse, electrocardiograph and oximetry were made at various times on this group of patients.

The results in this group of cardiac patients were quite different from those in the pulmonary disease group in that every patient selected tolerated the exposure to 8,000 feet without apparent difficulty. Average resting and post-exercise heart rates were minimally increased by exposure to altitude and the increases after the meal were in the expected range. Blood pressure, vital capacity and expiratory flow rates were unaffected by altitude exposure. Oxygen saturation dropped slightly as expected; otherwise, no clear alteration in the variables studied were observed in the cardiac group (Table 5).

Discussion

The major environmental stresses caused by exposure to moderate altitude are hypoxia and expansion of gases due to the reduced barometric pressure. At sea level the barometric pressure is 760 mm of mercury or 14.7 pounds per square inch. At 10,000 feet altitude the barometric pressure is approximately one-third that at ground level. At sea level oxygen exerts a pressure of 160 mm of mercury; at 10,000 feet, 107 mm of mercury. To compensate for this decrease in barometric pressure, hyperventilation and other physiological adjustments take place. At 10,000 feet, oxygen saturation is normally about 90 per cent. In persons with cardio-respiratory impairment, the effects of altitude stresses may become apparent at a much lower altitude than in normal people.

The adverse reactions which occurred in the eight patients with pulmonary disease were as follows: hypoxia (three cases), inability to hyperventilate (three cases), hypoventilation (one case), and expansion of trapped gases (one case). Three of these four factors could have been prevented by the administration of supplemental oxygen and indeed these reactions were treated by oxygen administration. The fourth factor, the expansion of trapped gases, can be relieved only by descent.

TABLE 5.—*Physiological Responses to Altitude of Patients With Heart Disease*

	2000 feet		8000 feet	
	Mean	*Range*	*Mean*	*Range*
Heart rate (beats per minute):				
At rest	83	66-112	86	66-120
After exercise	107	75-150	109	75-150
Postprandial:				
At rest	—	—	90	65-130
After exercise	—	—	116	82-150
Blood pressure at rest:				
Systolic	132	104-240	130	98-210
Diastolic	79	48-120	79	58-160
Oxygen saturation (oximeter), per cent				
At rest	94	83-100	92	82-100
After exercise	—	—	90	75-100
Maximum expiratory flow rate (liters per minute)	233	48-430	238	90-410

Vital capacity was of little value in predicting altitude tolerance, as seven of the 14 patients with 50 per cent or less capacity tolerated the altitude well. The x-ray appearance of the chest was also of little value in predicting the ability to tolerate altitude. Of the many determinations and examinations performed on the patients the oxygen saturation, the maximal voluntary ventilation and the ability to hyperventilate proved most useful. Subjects in whom arterial oxygen saturation was below 90 per cent at ground level tolerated altitude tolerance poorly. This result was anticipated in that such subjects are relatively hypoxic at ground level and have an oxygen saturation equivalent to that of normal persons at 10,000 feet. Likewise, if the maximal voluntary ventilation is below 40 liters per minute, there is little breathing reserve and hyperventilation cannot be sustained. Hypoxia and carbon dioxide retention may occur.

If any of the tests indicate severe impairment, a person should be advised against altitude exposure until more thoroughly investigated. If he insists on traveling, an attendant trained in oxygen administration and acquainted with detecting danger signs should accompany the patient. Such an attendant can administer oxygen when necessary and observe the subject for apnea and other phenomena.

Use of a full battery of tests and examination is justified for any patient with severe pulmonary defects in order to determine the ability to ventilate and to maintain normal oxygen saturation. The measurements of the forced expiratory flow rate, the maximal voluntary ventilation and the oxygen saturation provide such information. If a full battery of tests is not feasible, it is recommended that the chest be examined by auscultation with emphasis on distribution and intensity of breath sounds. An exercise test should be done and the forced vital capacity measured.

The difference in the altitude tolerance between the patients with pulmonary and those with cardiac disease was not entirely unexpected. All 27 of those with cardiac disease tolerated the altitude well for exposures averaging one and a half hours. Those with cardiac disease did not have significant pulmonary dysfunction and were able to increase their ventilation without difficulty. Also, if pulmonary edema or congestion is absent, gas exchange and a satisfactory oxygen saturation are adequately maintained. Consequently, very little additional burden is put upon the heart to maintain adequate tissue oxygenation. It should be pointed out that the maximum altitude used in these experiments was 8,000 feet. Higher altitudes undoubtedly can be the cause of difficulties for patients with cardiac impairment.

Admittedly, conditions in an altitude chamber are not a perfect simulation of those encountered in the mountains, on a commerical airliner, in a car or on a train. If anything, the effects in a chamber are less stressful in that factors of climate, environment, terrain, vibration and physical activity are not present.

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